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(56) Documents Cited
GB 2239101 A GB 2175705 A GB 2075762 A
EP 0219359 A1

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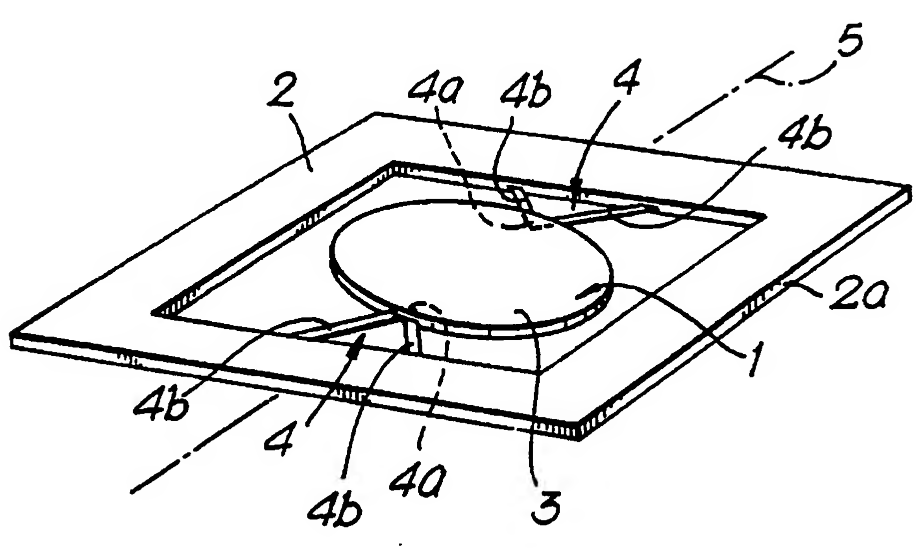
WPI

(54) Silicon micro-mirror unit

(57) A micro-mirror unit is made from a silicon wafer base 2 by micro machining steps which include doping the Si surface with boron and oxidising it; applying Al to this surface and etching to produce the mirror 3 and hinge 4 shapes; and finally the mirror 3 is separated from the base except for the supporting hinges 4 by a reactive ion etch and an anisotropic etch. The hinges have a reduced thickness in respect to the silicon base wafer and mirror, and have a generally V shape in plan. Their support points define a pivotal axis for the mirror.

Fig.2.



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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

Fig.1A.

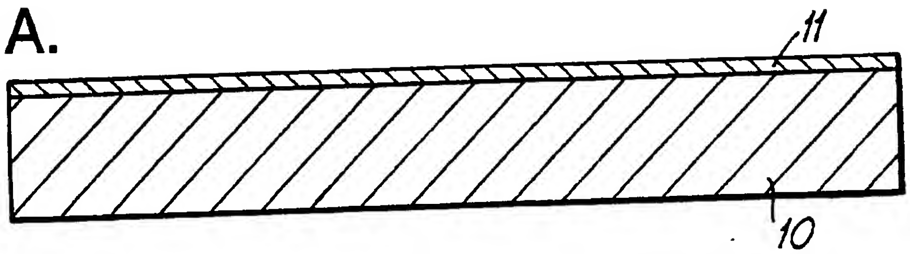


Fig.1B.

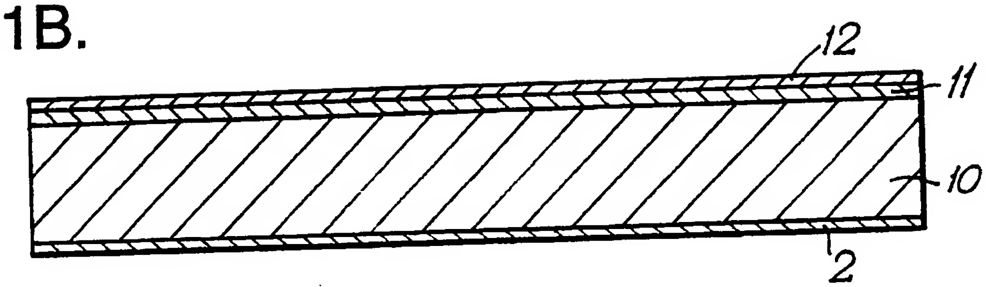


Fig.1C.

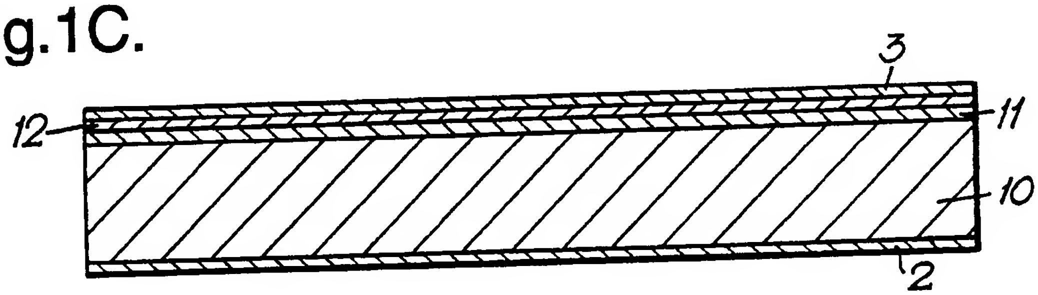


Fig.1D.

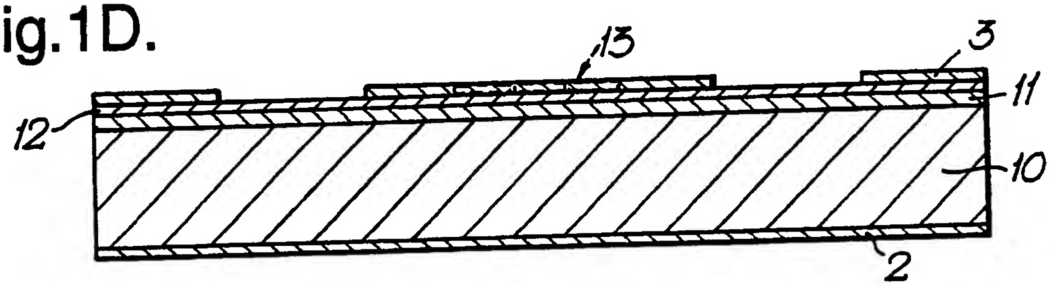


Fig.1E.

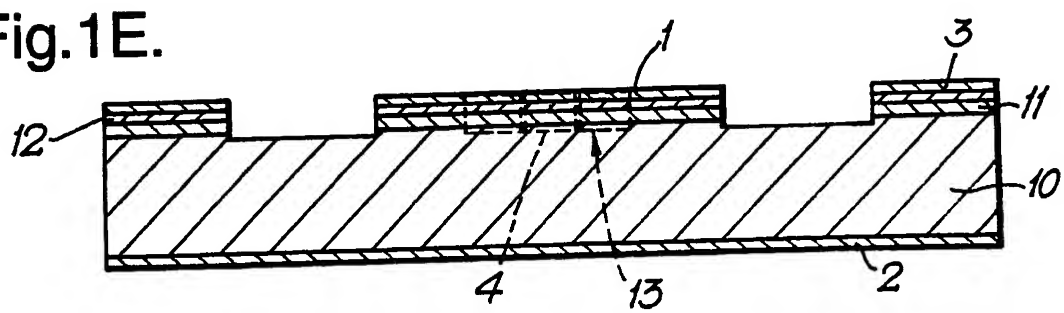


Fig.1F.

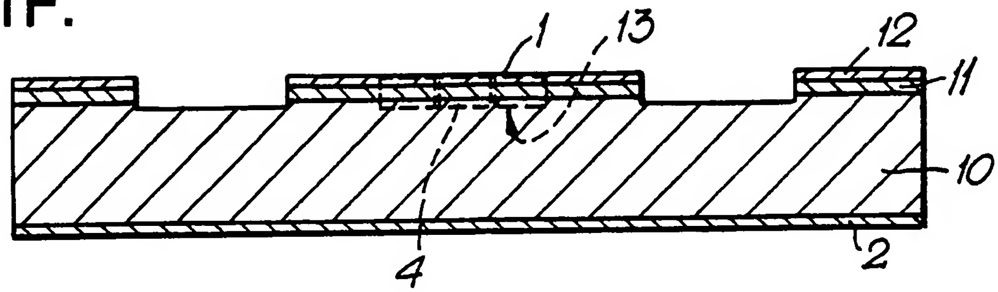


Fig.1G.

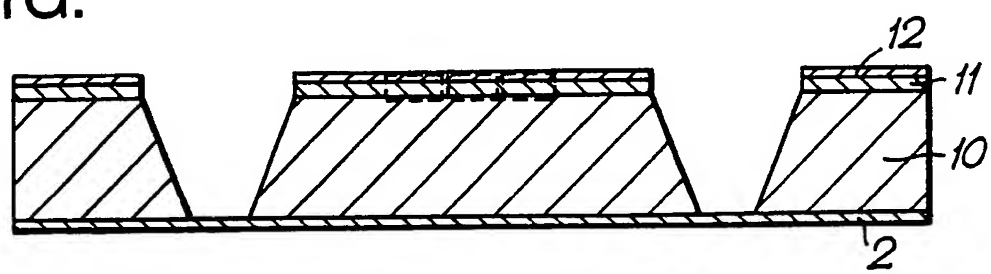


Fig.1H.

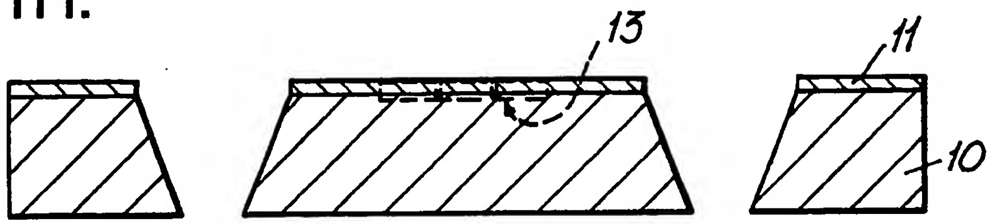


Fig.1J.

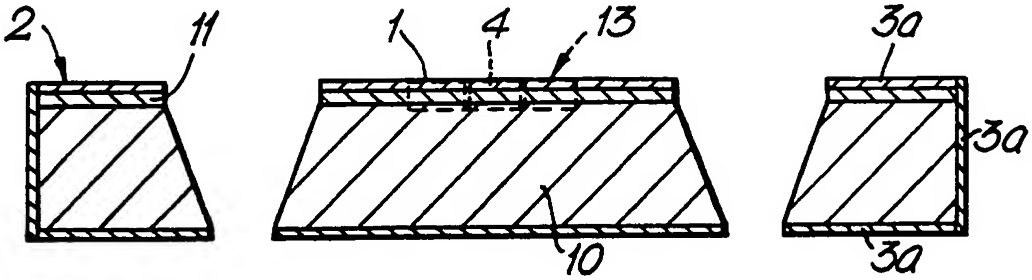


Fig.2.

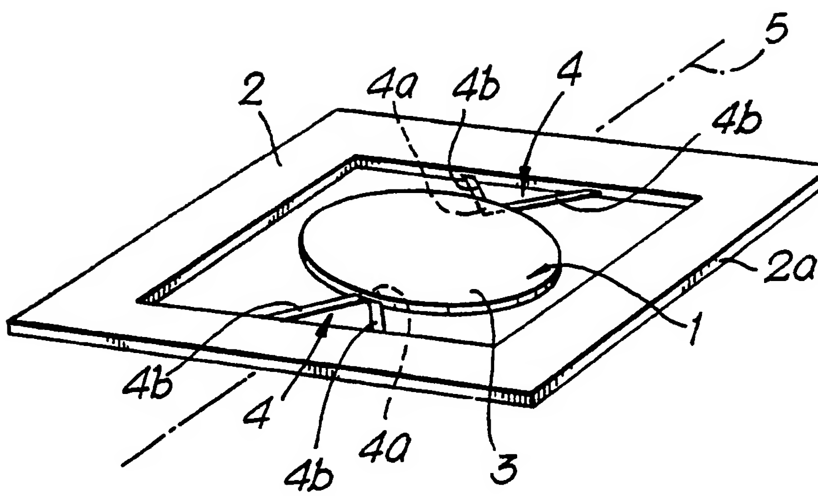
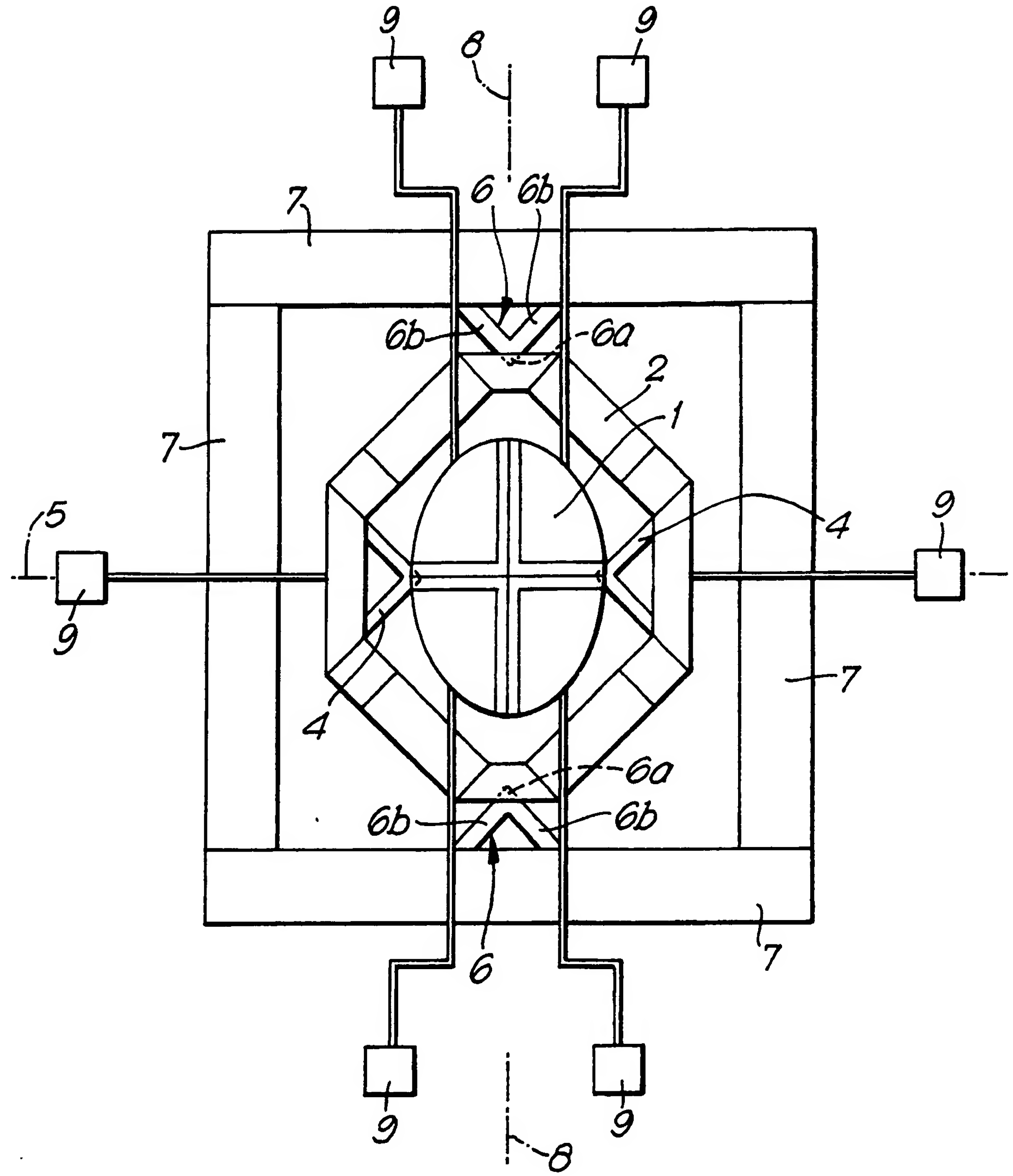


Fig.3.



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MICRO-MIRROR UNIT

This invention relates to a micro-mirror unit particularly, but not exclusively, suitable for use in an optical inter satellite link, and to a process for manufacturing such a micro-mirror unit.

Earth orbiting satellite networks require an optical link to be maintained between them during operation, for communication purposes, This link may take the form of a modulated laser beam which is aimed from one satellite to another by a mirror pointing system. This requires considerable accuracy because the distances between satellites may be very large and they will move relative to each other at high speeds if they occupy different orbits. Current mirror pointing systems are bulky, heavy and very expensive.

There is thus a need for a micro-mirror unit which is relatively small in size, light in weight and cheap in comparison with conventional mirror units utilised in inter satellite link mirror pointing systems, and to an improved process for manufacturing such micro-mirror units.

According to one aspect of the present invention there is provided a process for manufacturing a micro-mirror unit including the steps of, diffusing boron atoms into a least a surface layer of a silicon wafer to form a boron doped surface layer, oxidising surfaces of the wafer, depositing a layer of aluminium onto the oxidised boron doped surface of the wafer, etching a plan view of the desired mirror and

at least two hinges securing it to the surrounding wafer material, onto and into the wafer to a depth greater than the depth of the boron doped surface layer, removing the aluminium layer, etching the exposed undoped silicon of the wafer to undercut the at least two hinges and to separate the mirror from the remaining wafer material, removing oxide from the oxidised surfaces of the wafer, and depositing aluminium on the outer surfaces of the wafer to provide a reflective surface on the mirror and electrical connection areas on the wafer.

Advantageously a concentration of boron atoms in the range of from $7x10^{19}$ to $1x10^{20}$ atoms per cubic centimetre is diffused into the silicon to a depth in the range of from 5 to 25 microns.

Preferably substantially 7×10^{19} boron atoms per cubic centimetre are diffused into the silicon to a depth in the range of from 13 to 15 microns.

Conveniently the silicon wafer utilised is substantially plane and has a crystalline structure orientated in the (100) direction, and in which the plan view is aligned with the (110) direction of the wafer prior to etching.

Advantageously the layer of aluminium on the oxidised surfaces of the wafer has a thickness of substantially 1 micron and is applied by sputtering.

Preferably the plan view is etched onto the aluminium layer photolithographically.

Conveniently the plan view is dry etched through the aluminium layer into the silicon in a reactive ion etcher using a SF_6 plasma, and with the plan view on the aluminium layer acting as an etch mask.

Advantageously the exposed undoped silicon is anisotropically etched using an ethylene diamine pyrocatechol solution.

Preferably the micro-mirror unit is mounted on a base silicon wafer which carries aluminium electrodes and the electrodes are connected to the electrical connection areas.

Conveniently the mirror has, in plan view, a substantially elliptical shape.

Conveniently the at least two hinges are two undercut hinges formed at locations in which they provide the mirror with a first pivotal axis.

Preferably two further undercut hinges are formed at locations on the silicon wafer such as to provide the mirror with a second pivotal axis substantially at right angles to said first pivotal axis.

Conveniently the further hinges are connected between the wafer and a cut surround to the mirror, to which surround the mirror is connected by said at least two hinges.

Advantageously each hinge has, in plan view, a substantially V shape with the apex thereof being directed towards the mirror.

According to a further aspect of the present invention there is provided a micro-mirror unit having a silicon mirror hingedly connected to, integral with and spaced from a silicon base, wherein the mirror has a reflective surface, is integral with and is connected to the silicon base by means of at least two silicon hinges which are so located to provide the mirror with a first pivotal axis, the hinges being made of silicon and having, in plan, a substantially V shape with an apex connected to the mirror and with two limbs connected at their ends to the silicon base and with said at least two hinges each being undercut so as to be smaller in thickness than said silicon base.

Preferably the mirror is, in plan, substantially elliptical in shape.

Conveniently the micro-mirror unit has two further undercut silicon hinges forming part of and integral with the mirror and silicon base and connected between the base and a freely suspended silicon surround to the mirror, to which surround the mirror is connected by said at least two hinges, and with said two further hinges being smaller in thickness than said silicon base.

Advantageously said two further hinges each have in plan a substantially V shape with an apex connected to the surround and two limbs connected at their ends to the silicon base, and wherein said two further hinges are located so as to provide a second pivotal axis for the mirror, which second pivotal axis is substantially at right angles to said first pivotal axis.

Preferably the or each hinge is smaller in thickness than the thickness of the mirror.

For a better understanding of the present invention, and to show how the same may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, in which:

Figures 1A to 1J are diagrammatic cross-sectional views through a micro-mirror unit showing successive steps in the manufacturing process according to the present invention.

Figure 2 is a diagrammatic perspective view from above of a micro-mirror unit made according to a process of the present invention and

Figure 3 is a diagrammatic plan view from above of a further embodiment of a micro-mirror unit made according to the process of the present invention.

A micro-mirror unit made according to the process of the present invention, as shown in Figure 2 of the accompanying drawings, is made from silicon and is in the form of a silicon mirror 1 hingedly connected to, integral with and space from a silicon base or surround 2. The mirror 1 has a reflective surface 3 preferably made of aluminium and preferably is elliptical in shape as illustrated. The mirror 1 is integral with and is connected to the silicon base or surround 2 by means of two silicon hinges 4 which are so located to provide the mirror 1 with a first pivotal axis. In the embodiment illustrated in Figure 1 the hinges are located diametrically opposite

one another on opposite sides of the elliptical shaped mirror 3 to provide a pivot axis 5 running through the two hinges 4.

The hinges 4 are also made of silicon and preferably, as illustrated, each have, in plan, a substantially V shape with an apex 4a connected to the mirror 1 and with two limbs 4b connected at their ends to the silicon base or surround 2. Each hinge 4 and the mirror 1 are undercut with respect to the silicon base or surround 2. Thus the thickness of the mirror 1 may be the same as the thickness of the silicon base or surround 2 whereas the thickness of each hinge 4 is less than that of the mirror 1 and silicon base or surround 2 to improve the flexibility of the hinges.

The micro-mirror unit shown in the second embodiment of Figure 3 is basically similar to that of Figure 2 and like parts will be given like reference numerals and not commented on any further in detail. However in the Figure 3 embodiment two further undercut silicon hinges 6 are provided which form part of and are integral with the mirror 1 and a silicon base 7. The further hinges 6 are connected between the base 7 and the freely suspended silicon surround 2 to the mirror 1. The mirror 1 is connected to the surround 2 by the two hinges 4 as aforesaid.

In the embodiment of Figure 3 the two further hinges 6 also each have in plan a substantially V shape with an apex 6a connected to the surround 2 and two limbs 6b connected

at their ends to the silicon base 7. The hinges 6 are located so as to provide a second pivotal axis 8 for the mirror 1, which second pivotal axis 8 is substantially at right angles to the first pivotal axis 5. Preferably the or each hinge 4, 6 is smaller in thickness than the thickness of the mirror 1 and thickness of the base 7.

Such a mirror unit as shown in Figure 3 has a mirror 1 which is steerable through two axes. This mirror 1 may be made movable in any convenient manner such as by electro static drive means 9.

The process of the present invention for manufacturing the micro-mirror unit utilises silicon micro machining techniques. Firstly a basic silicon wafer 10 having an outline size such as that of the base or surround 2 in the Figure 2 embodiment and that of the base 7 in the Figure 3 embodiment and having a plane form with a crystalline structure orientated in the (100) direction is treated to diffuse boron atoms into at least a surface layer of the silicon base wafer to form a boron doped surface layer 11 as shown in Figure 1A.

A high concentration of boron atoms, in the range of from $7x10^{19}$ to $1x10^{20}$ atoms per cubic centimetre, preferably substantially $7x10^{19}$ atoms per cubic centimetre were diffused into the silicon wafer to a depth in the range of from 5 to 25 microns, preferably from 13 to 15 microns. The surfaces of the silicon wafer forming the base or surround 2 or 7 were then oxidised, preferably in a furnace

to form an oxidised layer 12 as shown in Figure 1B. Following this a layer of aluminium was deposited onto the surface of the oxidised boron doped layer 12 of the wafer as shown in Figure 1c. Preferably the layer of aluminium 3 on the oxidised surfaces 12 of the wafer 10 is applied by sputtering and has a thickness of substantially 1 micron.

A plan view 13 of the desired shape of mirror 1 and at least two hinges 4 securing it to the surrounding wafer material is aligned with the (110) direction of the wafer 12 and is then etched onto the aluminium layer 3 and into the silicon wafer to a depth greater than the depth of boron doped surface layer 11. This plan view is etched onto the aluminium layer 3 photolithographically and the plan view is dry etched through the aluminium layer into the silicon in a reactive ion etcher using a SF_6 plasma and with the plan view on the aluminium layer acting as an etch mask, as shown in Figures 1D and 1E.

The dry etch using SF_6 gas is carried out at a pressure of about 40mtorr using a power of 200 watts.

The remaining aluminium layer 3 is then removed as shown in Figure 1F and the exposed undoped silicon of the wafer 10 is etched to undercut the at least two hinges and to separate them and the mirror from the remaining silicon wafer material as shown in Figure 1G. The exposed undoped silicon is anisotropically etched using an ethylene diamine pyrocatechol solution or potassium hydroxide. In such an etching method the silicon 10 is etched in a crystal orientation dependent manner and features may be passivated

in the etchant by the boron doping in the silicon. In this way it is possible to undercut the at least two hinges and to separate them and the mirror from the remaining wafer material so that the hinges and mirror become free hanging.

Thus in the Figure 2 embodiment the mirror 1, and two hinges 4 are made to be freely suspended with respect to the silicon wafer base or surround 2 of which they form part. In this embodiment the hinges 4 are approximately 13 microns thick in order to allow freedom of movement of the mirror 1 through the desired angular range which is approximately plus or minus 3 degrees. The silicon base or surround 2 is substantially 380 microns thick as is the mirror 1.

In the Figure 3 embodiment the silicon base wafer 7 also is approximately 380 microns thick and is formed, using the process outlined above, such as to provide a freely suspended surround 2 of substantially the same thickness connected to the base 7 by the substantially V plan undercut hinges 6 which are approximately 13 microns in thickness and with the mirror 1, which also has a thickness of substantially 380 microns, which is connected to the surround 2 and freely suspended with respect thereto, by the hinges 4 which are substantially 13 microns thick. The anisotropic etch is continued until the hinges have been undercut to the desired thickness and the mirror itself has been freed from the surround.

The undercutting is due to the fact that the high order crystal planes in the silicon have been exposed to

the ethylene diamine pyrocatechol etch solution and these planes have etched at an enhanced rate compared to the (111) planes which define the surrounding structure. The undercutting does not compromise the overall structure integrity of the mirror unit. The mirror 1 is kept as thick as possible in relation to the thickness of the overall silicon base wafer (ie substantially 380 microns in thickness), to preserve rigidity and therefore keep the mirror surface optically flat and stable. The hinges constrain motion of the mirror 1 to the desired axis 5 and/or 6.

After the anisotropic etch has been carried out the oxidised layer 12 is removed as shown in Figure 1A and aluminium 3a is deposited on the outer surfaces of the wafer 10 as shown in Figure 1J to provide a reflective surface 3a on the mirror 1 and electrical connection areas such as 2a in Figure 1 on the base 2.

A plurality of micro-mirror units can be formed on a single wafer and separated therefrom individually. For use the micro-mirror unit may be mounted on a base silicon wafer which carries aluminium electrodes and the electrodes can be connected to the electrical connection areas. Conveniently the unit is mounted on a base silicon wafer using fused quartz spacers which preferably have a length of 100 microns. If desired the mounted micro-mirrored unit may in turn be mounted in a hybrid chip package and the electrode contacts wire bonded to pins on the chip.

CLAIMS

1. A process for manufacturing a micro-mirror unit including the steps of, diffusing boron atoms into a least a surface layer of a silicon wafer to form a boron doped surface layer, oxidising surfaces of the wafer, depositing a layer of aluminium onto the oxidised boron doped surface of the wafer, etching a plan view of the desired mirror and at least two hinges securing it to the surrounding wafer material, onto the aluminium layer and into the wafer, to a depth greater than the depth of the boron doped surface layer, removing the aluminium layer, etching the exposed undoped silicon of the wafer to undercut the at least two hinges and to separate the mirror from the remaining wafer material, removing oxide from the oxidised surfaces of the wafer, and depositing aluminium on the outer surfaces of the wafer to provide a reflective surface on the mirror and electrical connection areas on the wafer.

2. A process according to claim 1, in which a concentration of boron atoms in the range of from $7x10^{19}$ to $1x10^{20}$ atoms per cubic centimetre is diffused into the silicon to a depth in the range of from 5 to 25 microns.

3. A process according to claim 2, in which substantially 7×10^{19} boron atoms per cubic centimetre are diffused into the silicon to a depth in the range of from 13 to 15 microns.

4. A process according to any one of claims 1 to 3, in which the silicon wafer utilised is substantially plane and

has a crystalline structure orientated in the (100) direction, and in which the plan view is aligned with the (110) direction of the wafer prior to etching.

5. A process according to any one of claims 1 to 4, in which the layer of aluminium on the oxidised surfaces of the wafer has a thickness of substantially 1 micron and is applied by sputtering.

6. A process according to any one of claims 1 to 5, in which the plan view is etched onto the aluminium layer photolithographically.

7. A process according to any one of claims 1 to 6, in which the plan view is dry etched through the aluminium layer into the silicon in a reactive ion etcher using a SF_6 plasma, and with the plan view on the aluminium layer acting as an etch mask.

8. A process according to any one of claims 1 to 7, in which the exposed undoped silicon is anisotropically etched using an ethylene diamine pyrocatechol solution.

9. A process according to any one of claims 1 to 8, in which the micro-mirror unit is mounted on a base silicon wafer which carries aluminium electrodes, and the electrodes are connected to the electrical connection areas.

10. A process according to any one of claims 1 to 9, in which the mirror has, in plan view, a substantially elliptical shape.

11. A process according to any one of claims 1 to 10, in which the at least two hinges are two undercut hinges

formed at locations in which they provide the mirror with a first pivotal axis.

12. A process according to claim 11, in which two further undercut hinges are formed at locations on the silicon wafer such as to provide the mirror with a second pivotal axis substantially at right angles to said first pivotal axis.

13. A process according to claim 12, in which the further hinges are connected between the wafer and a surround to the mirror, to which surround the mirror is connected by said at least two hinges.

14. A process according to any one of claims 1 to 13, in which each hinge has, in plan view, a substantially V shape with the apex thereof being directed towards the mirror.

15 A process for manufacturing a micro-mirror unit substantially as hereinbefore described.

16. A micro-mirror unit having a silicon mirror hingedly connected to, integral with and spaced from a silicon base, wherein the mirror has a reflective surface, is integral with and is connected to the silicon base by means of at least two silicon hinges which are so located to provide the mirror with a first pivotal axis, the hinges being made of silicon and each having, in plan, a substantially V shape with an apex connected to the mirror and with two limbs connected at their ends to the silicon base, and with said at least two hinges each being undercut so as to be smaller in thickness than said said silicon base.

17. A micro-mirror unit according to claim 16, wherein the mirror is, in plan, substantially elliptical in shape.

18. A micro-mirror unit according to claim 16 or claim 17, having two further undercut silicon hinges forming part of and integral with the mirror and silicon base and connected between the base and a freely suspended silicon surround to the mirror, to which surround the mirror is connected by said at least two hinges, and with said two further hinges being smaller in thickness than said silicon base.

19. A micro-mirror unit according to claim 18, wherein said two further hinges each have in plan a substantially V shape with an apex connected to the surround and two limbs connected at their ends to the silicon base, and wherein said two further hinges are located so as to provide a second pivotal axis for the mirror, which second pivotal axis is substantially at right angles to said first pivotal axis.

20. A micro-mirror unit according to any one of claims 16 to 19, wherein the or each hinge is smaller in thickness than the thickness of the mirror.

21. A micro-mirror unit substantially as hereinbefore described and as illustrated in Figure 1 or Figure 2 of the accompanying drawings.

Patents Act 1977
E› niner's report to the Comptroller under Section 17 (The Search Report)

Application number
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Relevant Technical fields

(i) UK Cl (Edition L) G2J (JB7W3 JMH JMX)

(ii) Int Cl (Edition 5) G02B

Databases (see over)

(i) UK Patent Office

(ii) WPI

Search Examiner

R E HARDY

Date of Search

27 APRIL 1993

Documents considered relevant following a search in respect of claims ALL

Category (see over)	Identity of document and relevant passages		Relevant to claim(s)
X	GB 2239101 A	(GEC-MARCONI) see Figure 1	Claim 10 at least
X	GB 2175705 A	(STC) see Figure 1	Claim 10 at least
X	GB 2075762 A	(YOKOGAWA) see the Figures	Claim 10 at least
X	EP 0219359 A1	(BRITISH TELECOM) see Figure 2	Claim 10 at least

Category	Identity of document and relevant passages	Relevant to claim(s)

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family, corresponding document.

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